Rapid Prototyping & Manufacturing: Shortening the Path from Art to Part

by

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Rapid Prototyping (RP)

Agenda:

- Purpose of Briefing
- RP Technology Overview
- What Can RP Do For You ?
- Success Stories
- Where Are We Going With RP ?

Rapid Prototyping (RP)

Purpose of Briefing

- Provide an overview of and insight into the field of Rapid Prototyping.
- Inspire wider use of this technology for the purpose of improving the competitiveness and quality of our manufactured products.

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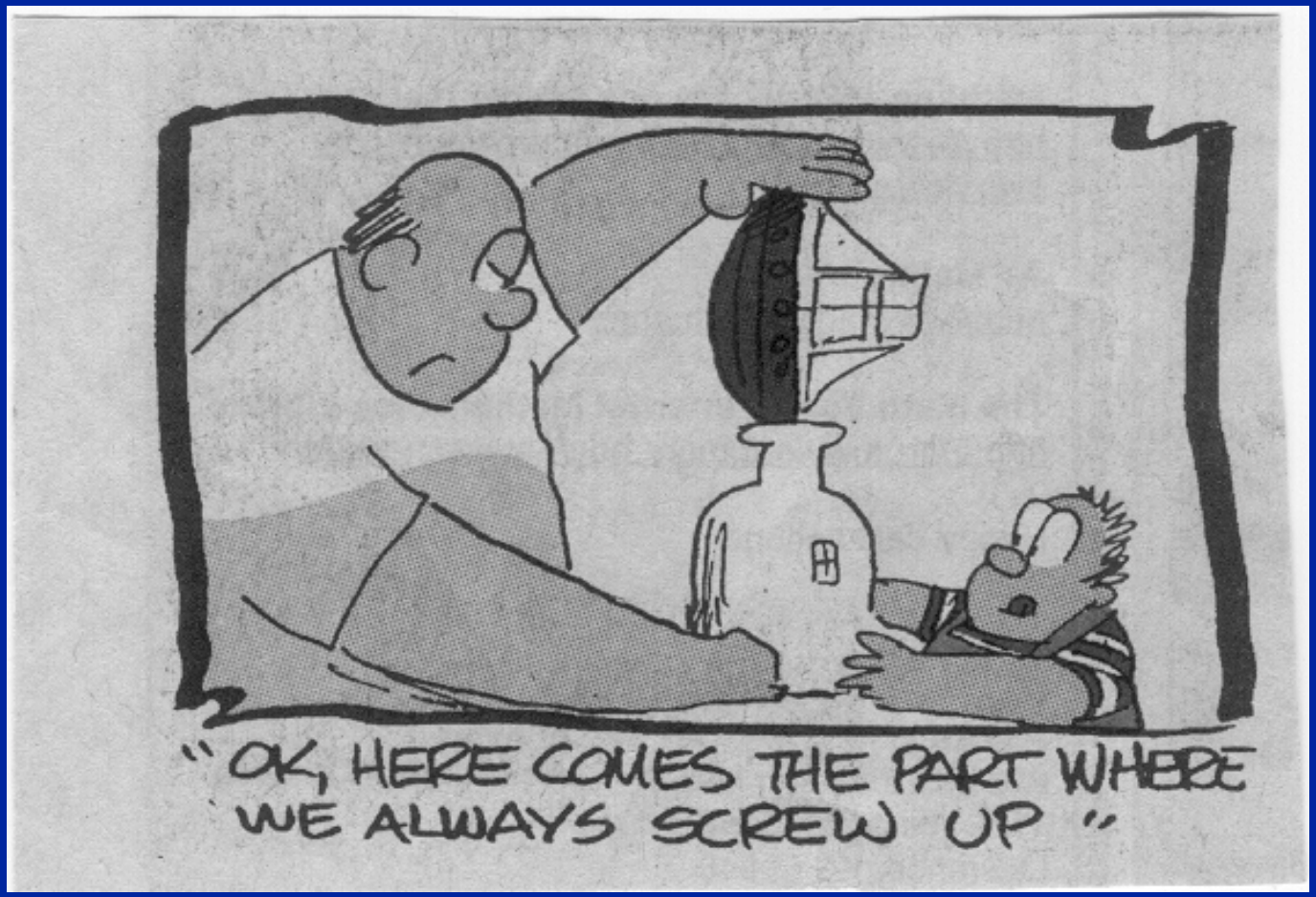
Rapid Prototyping (RP)

Purpose of Briefing

- Several Definitions for RP:
  - Fast Prototyping is old interpretation
  - Real definition: New additive process of automated part creation directly from CAD model
  - Differentiated from NC machining which is a subtractive process
  - Simplicity vs Complexity: 2D layers vs 5 axis NC programming
  - Is new automated NC software coupled with high-speed machining catching up?



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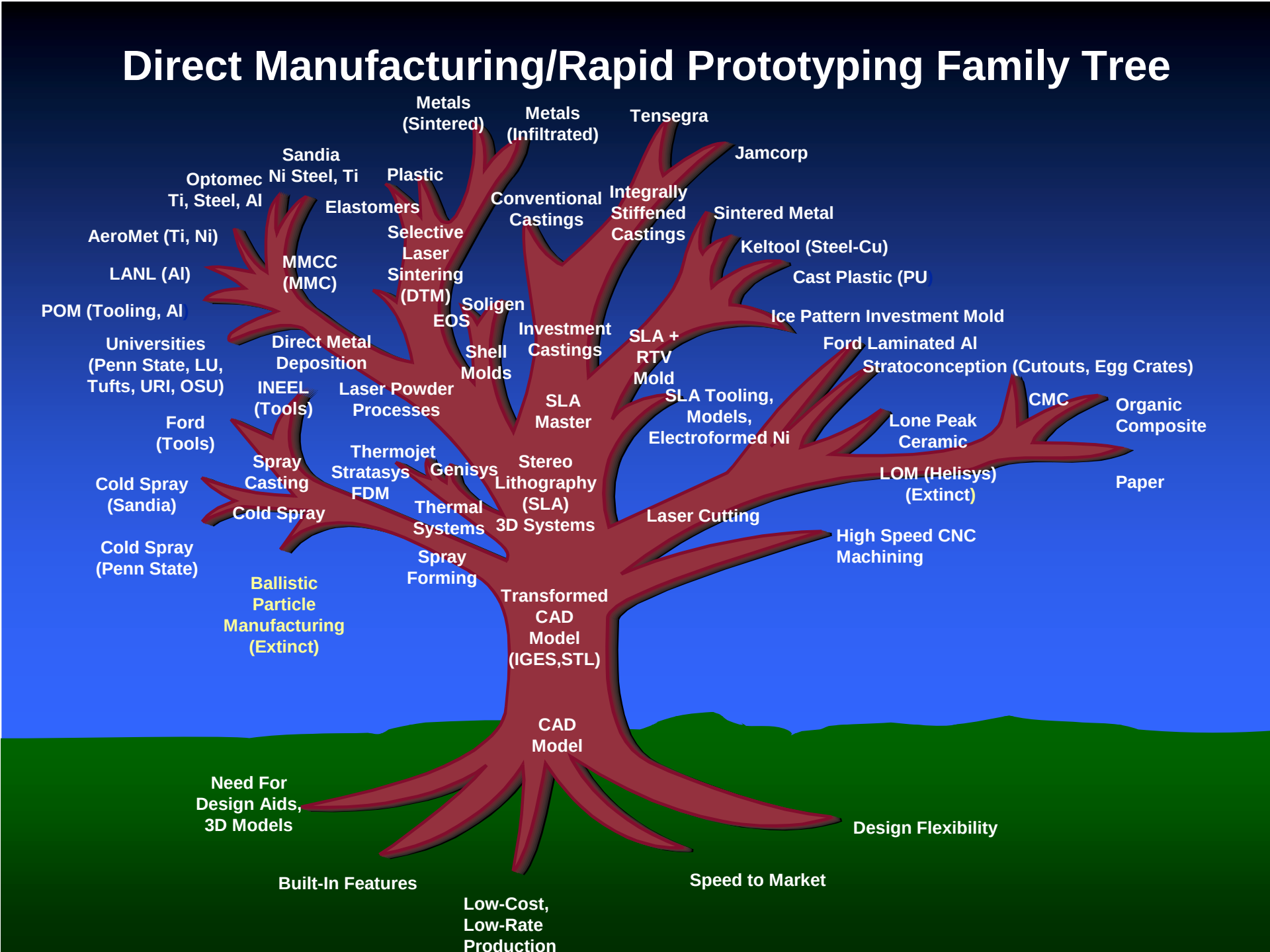
Direct Manufacturing/Rapid Prototyping Family Tree



Rapid Prototyping (RP)

Technology Overview

- Rapid Prototyping Technologies
  - Stereolithography (3D Systems)
  - Laminated Object Manufacturing by Cubic Tech. (Helisys)
  - Fused Deposition Modeling (Stratasys)
  - Desk Top Printers
  - Powder Metal RP Systems:
    - Selective Laser Sintering (DTM)
    - Optomec
    - Aeromet
    - POM
    - Optoform
    - Solidica
  - MEMS & Microfabrication
    - EFAB (Electrochemical fabrication)

Stereolithography, SLA

- **Laser Curing of Photopolymers, Layer by Layer**

ADVANTAGES

- **Tolerancing**
- **High Detail, thin walls**
- **Good Surface Finishes**
- **Lends itself to High Quality Rapid Manufacturing Techniques: RTV Molding, SLA Molds, Kel-Tool, Sheet Metal Forming tools**

DISADVANTAGES

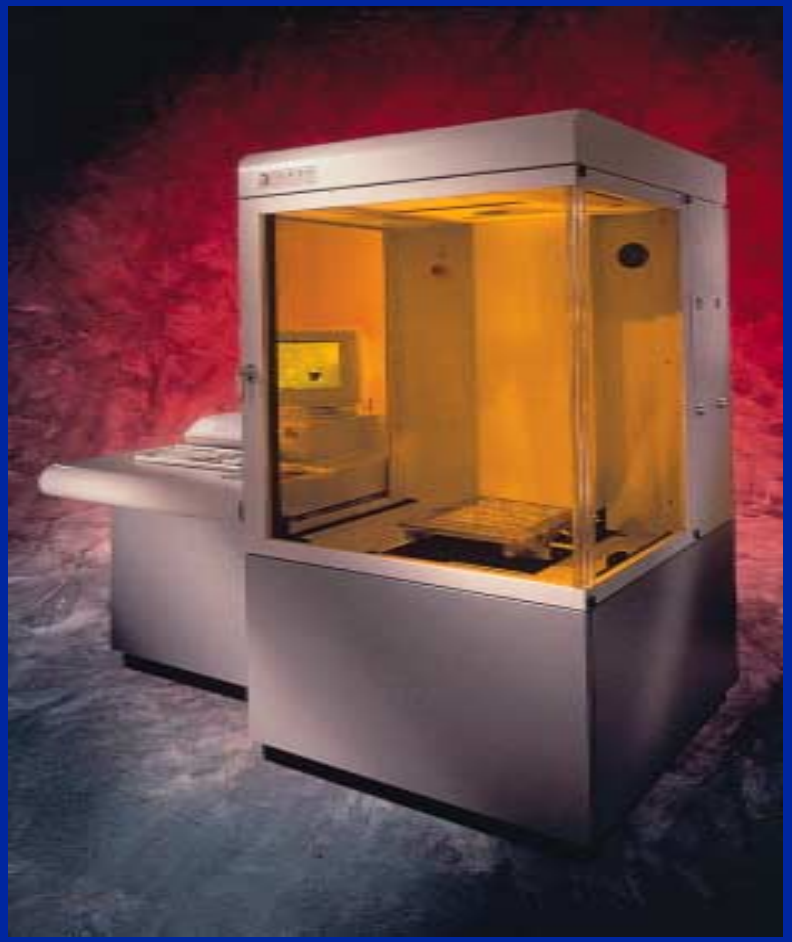
- **Requires Post Curing**
- **Limited Materials**
- **Additional Cleaning Chemicals and Related Safety Needs**
- **Limited Material Properties**

Stereolithography, SLA

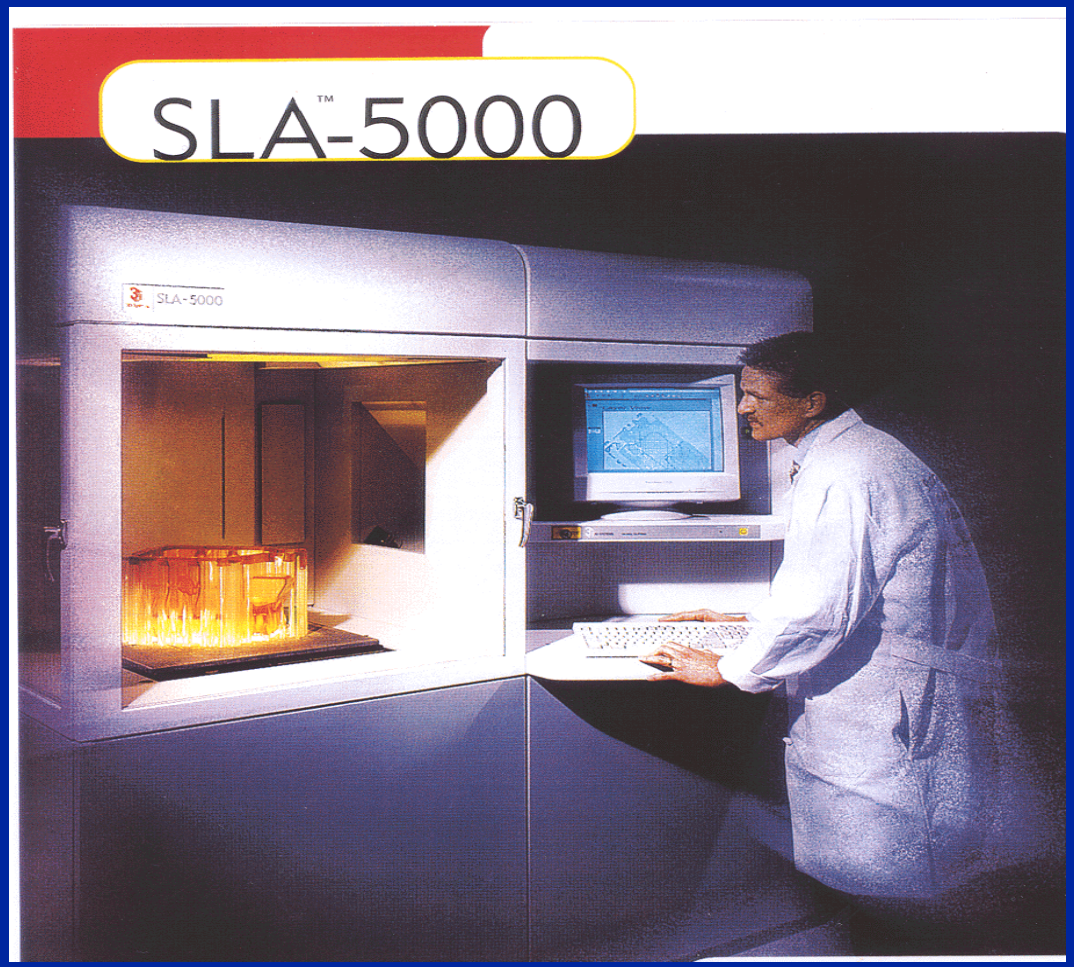
- **Applications:**
  - **Prototypes for design verification and testing**
  - **Patterns for casting and molding**
  - **Tools for pre- or low-production tooling**
  - **Parts for manufacturing aids, vendor solicitation and limited production runs**

Stereolithography

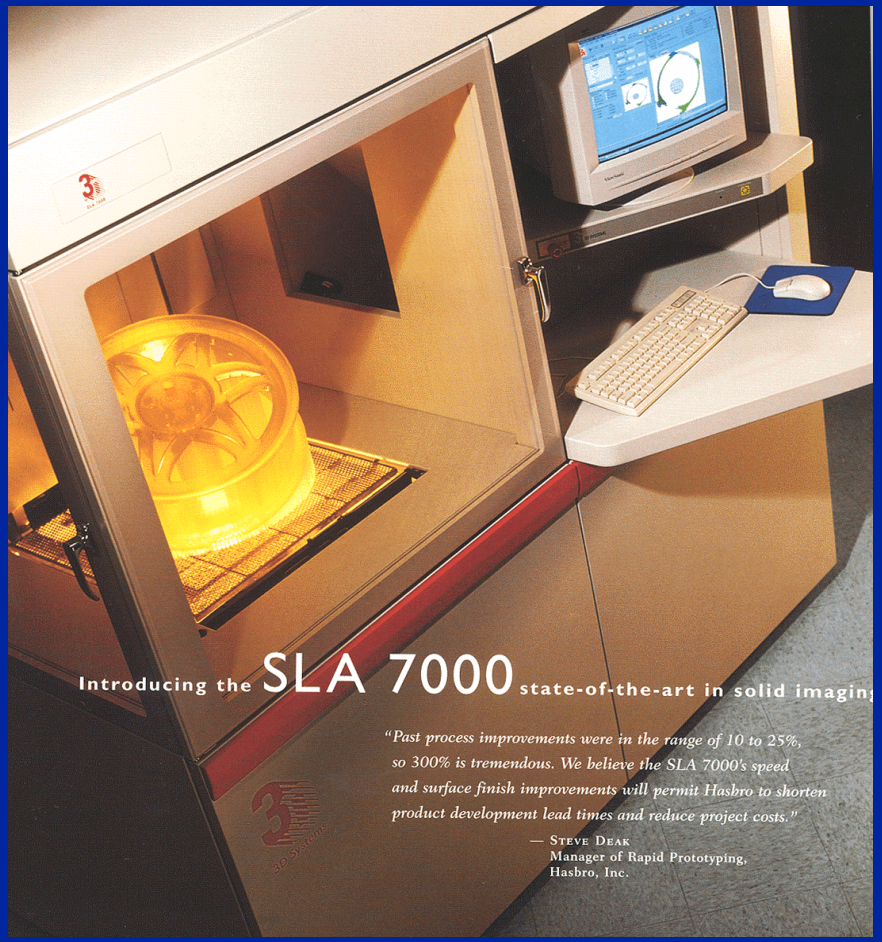
SLA MACHINES



SLA MACHINES



SLA MACHINES



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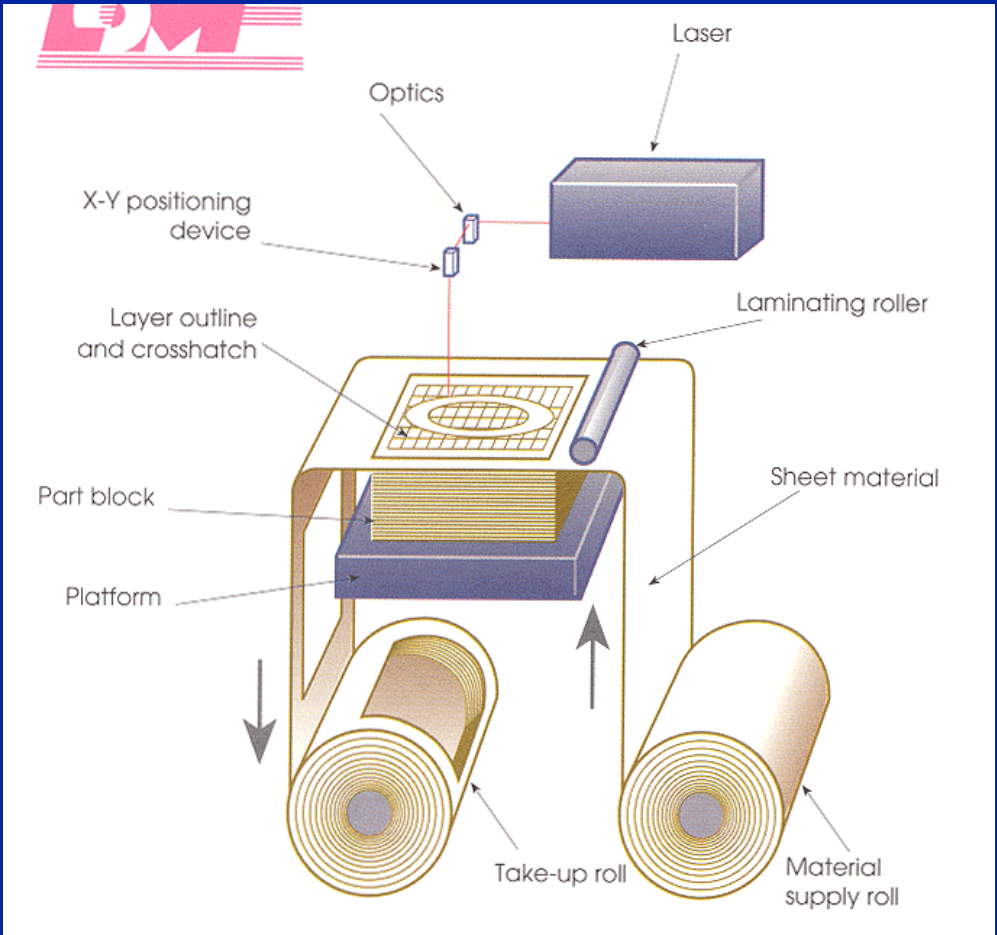
SLA MACHINES – The new Viper

- 

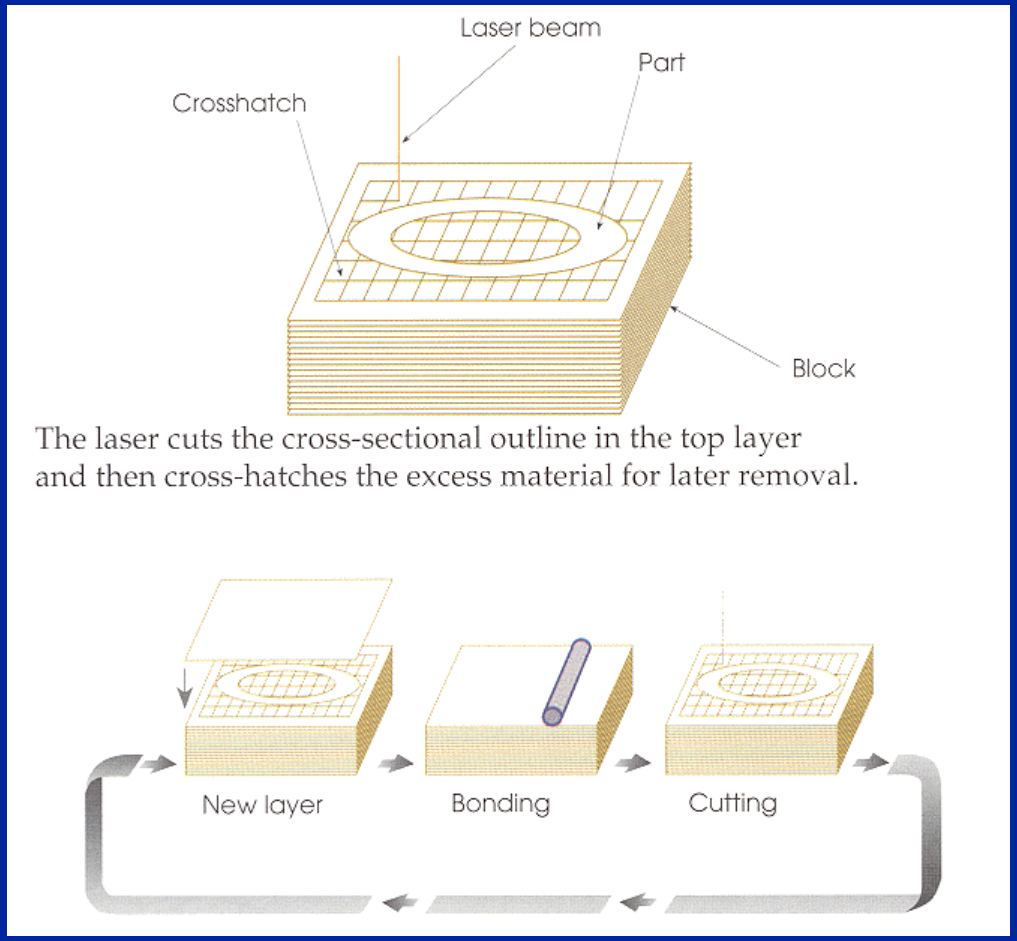
SLA MACHINES – The new Viper si2 system

- Dual resolution solid state laser.
- Lets you choose between standard resolution, for the best balance of build speed and part resolution, and high resolution (HR mode) for ultra-detailed small parts and features -- all from a carefully integrated digital signal processor (DSP) controlled high speed scanning system with a single, solid-state laser that delivers a constant 100 mW of available power throughout its 7,500-hour warranty life.

Laminated Object Manufacturing, LOM



Laminated Object Manufacturing, LOM



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Laminated Object Manufacturing, LOM

Laminated Object Manufacturing, LOM

ADVANTAGES

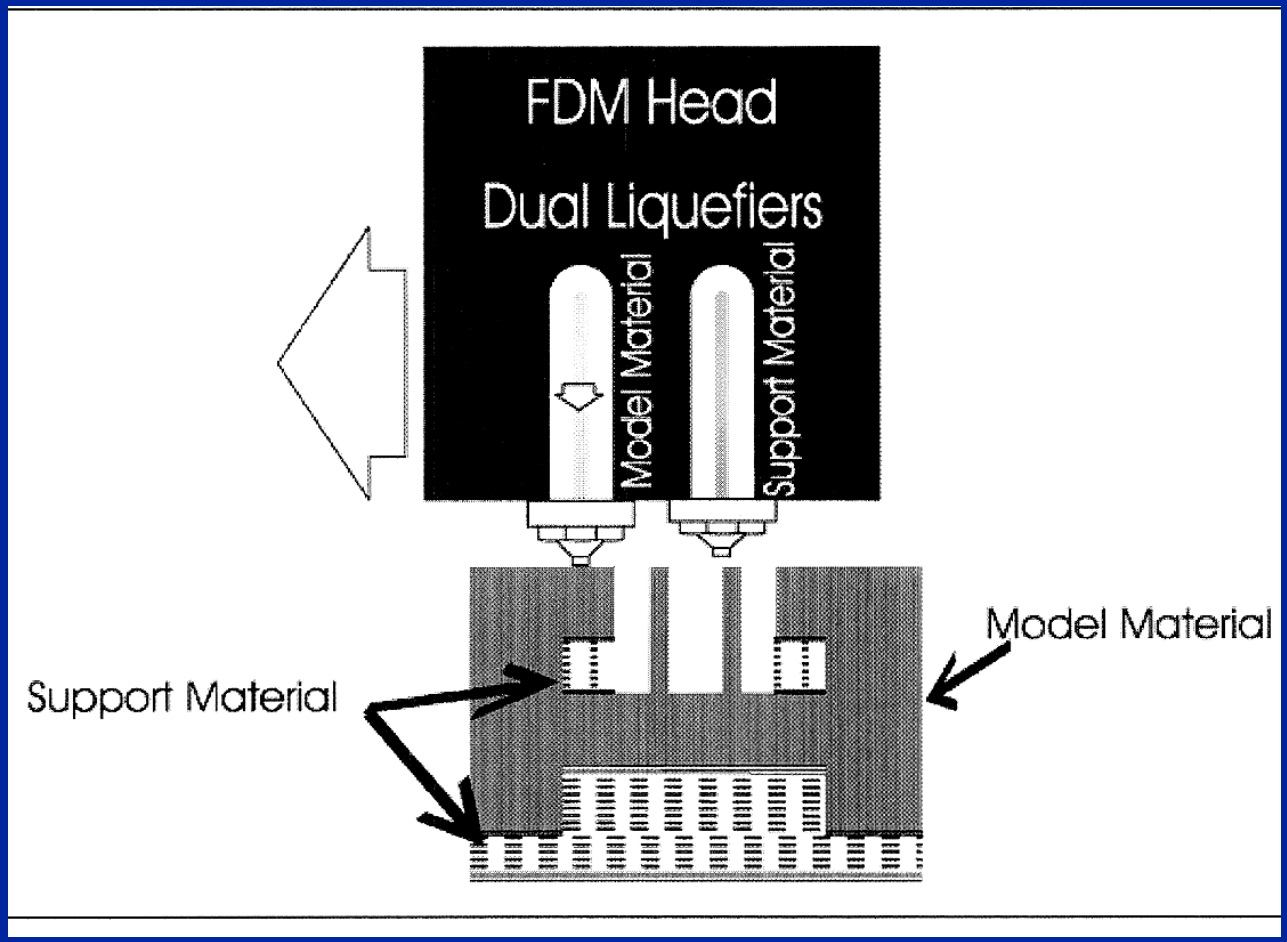
- No Post Curing
- No Material Phase Change, No Warpage
- Can Do Large Parts, Cheaper
- Non-toxic Materials
- Composite Material

Laminated Object Manufacturing, LOM

DISADVANTAGES

- Tolerancing
- Detail and Surface Finish
- Degradation under humid or wet environments
- Excess Material Removal Can Be Difficult, Internal Cavities
- Material Properties and Performance are Orientation Dependent

Stratasys's Fused Deposition Modeling



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Fused Deposition Modeling, FDM

ADVANTAGES

- Functional materials: ABS, Polyester, Polycarbonate, PPSF
- PPSF (Polyphenylsulfone) good to 200C (405F), high impact strength & tensile strength, resists gasoline, sulfuric acid, & antifreeze
- No post curing or other chemicals needed
- Fast on small, hollow geometries
- Office environment machines

FUSED DEPOSITION MODELING, FDM

DISADVANTAGES

- Surface finish is fair but not like fine finish
- Tolerancing has improved considerably
- Very small features, and Thin Walls are not as detailed as Stereolithography.
- Slow on dense, larger parts
- Material properties are orientation dependent – true for most RP systems.

FDM, Stratasys

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FDM Maxum

- **The fastest prototyping system offered by Stratasys, operating 50 percent faster than previous systems. Its WaterWorks™ soluble support systems offers virtually hands-free prototyping.**
- **Parts up to 600 x 500 x 600 mm (23.6 x 19.7 x 23.6 in) can be built**
- **Models can be produced within an accuracy of ± .127 (± .005 in) up to 127 mm (5 in.). Accuracy on models greater than 127 mm (5 in) is ± .0015 mm per millimeter (± .0015 in/in)**

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FDM Maxum

FDM Titan, Statasys

- **Parts up to 14 x 16 x 16 inches (355 x 406 x 406 mm) can be built**
- **Models are produced within an accuracy of ± .005 inch (± .127) up to 5 inches (127 mm). Accuracy on models greater than 5 inches (127 mm) is ± .0015 inch per inch (± .0015 mm/mm)high performance**
- **Engineering materials such as polycarbonate, ABS and sulfones.**

FDM Titan

Desk Top Printers

- Primarily Concept Modelers
- Accuracy
- Surface finish
- New Developments and Applications
  - Improvements in Accuracy
  - New Materials
  - Lower Prices

Z CORP

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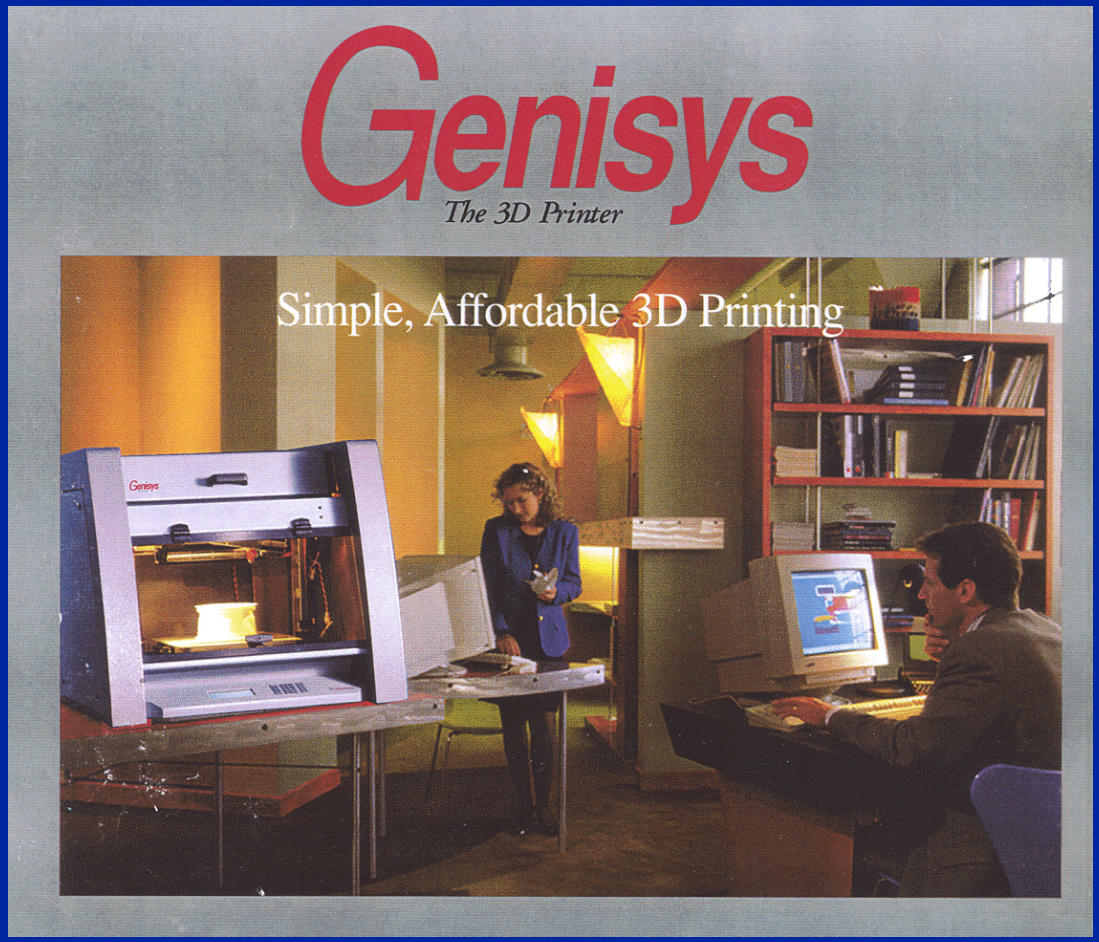
Genisys by Stratasys



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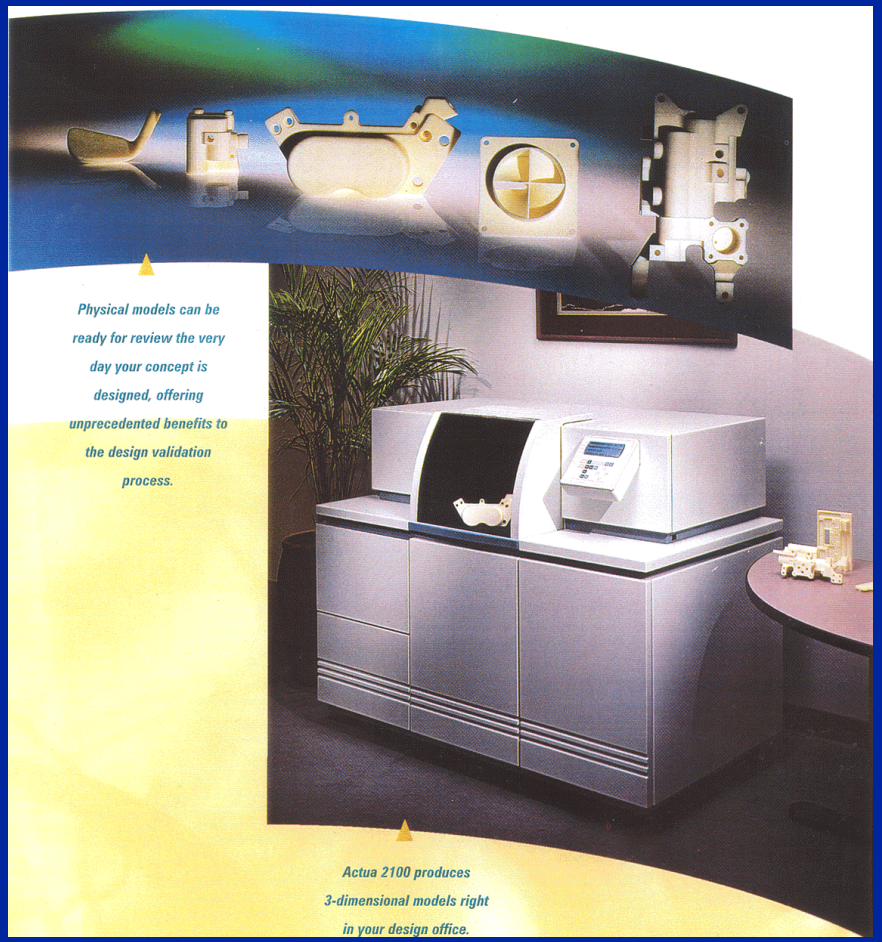
Prodigy by Stratasys

- **Prodigy system created as a traditional 3D printer, designers can test form, fit, and function with durable ABS parts**
- **Maximum size 203 x 203 x 305 mm (8 x 8 x 12 in)**
- **Parts are built of tough, durable ABS plastic in white (standard), blue, yellow, black, red or green. Custom colors available.**
- **One autoload cartridge with .95 kg (2.1 lbs) ABS model material. One autoload cartridge with .95 kg (2.1 lbs) support material.**

Prodigy by Stratasys

Actua/Thermojet



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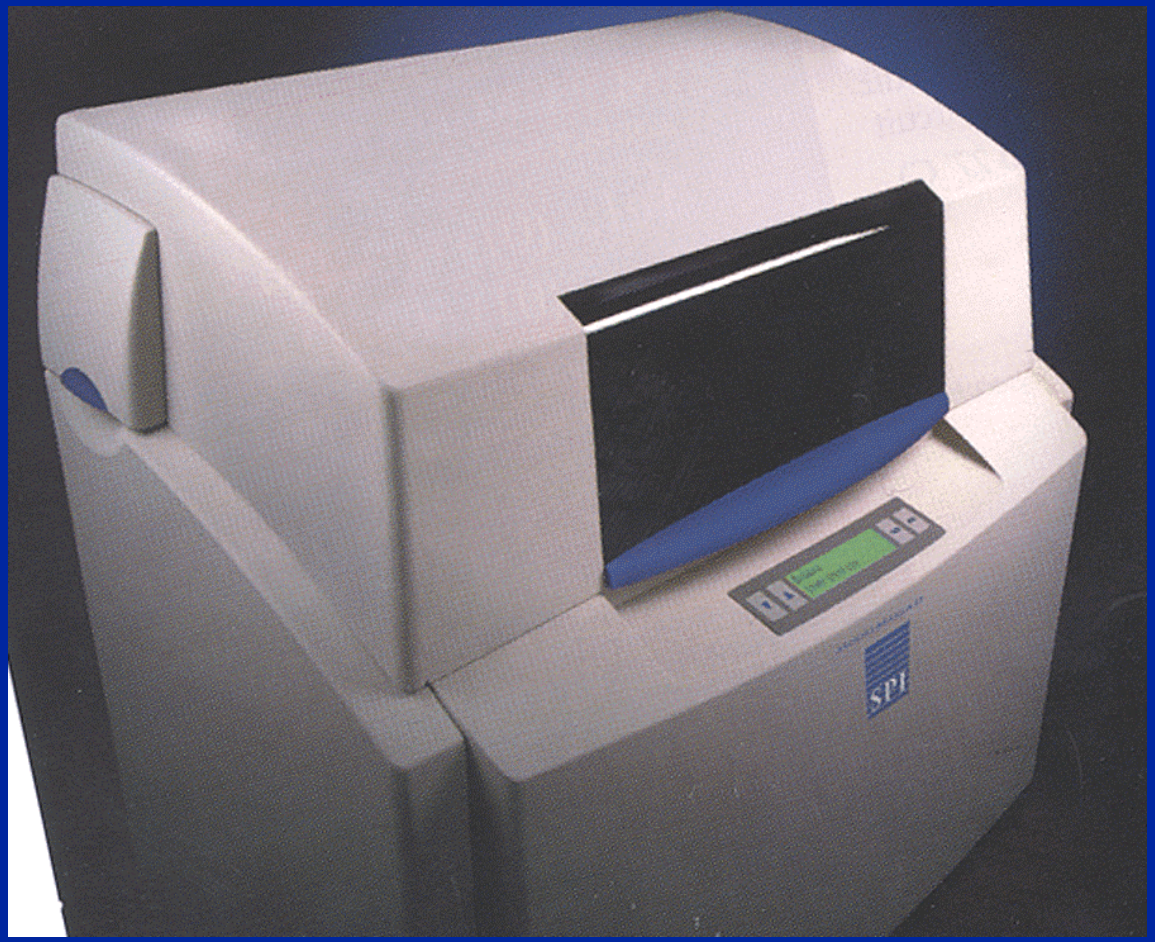
SANDERS PROTOTYPE



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Powder Metal RP Systems

Newest Developments in RP

- Selective Laser Sintering (DTM)
- Optomec
- Aeromet
- POM (Precision Optical Mfg)
- OptoForm
- Solidica

Selective Laser Sintering, SLS

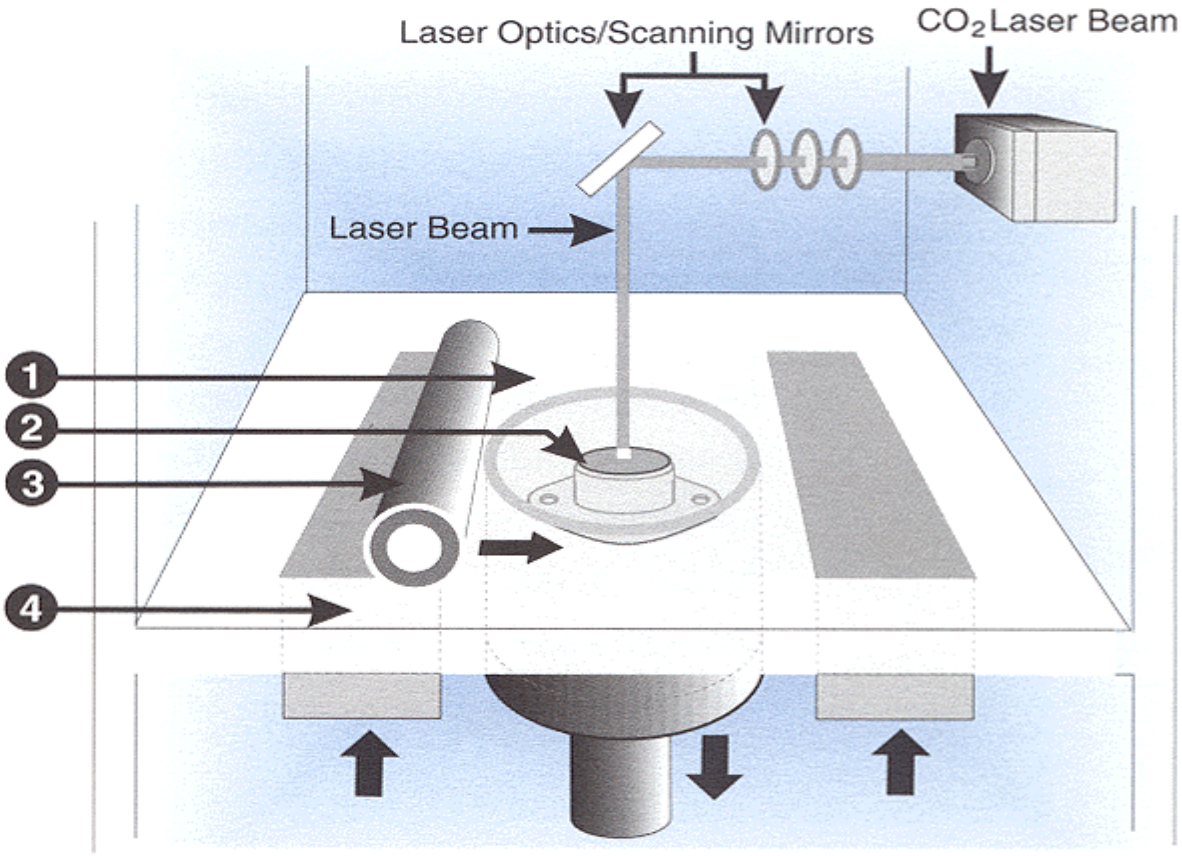
The SLS Process

1. A very thin layer of heat-fusible powder is deposited on top of the build cylinder

2. Laser "draws" a cross-section that matches the corresponding layer in the STL file, bonding the particles and fusing the adjacent layers

3. Roller mechanism deposits another powder layer

4. Support platform moves the part downward a layer at a time and the process repeats, until the part is fully formed



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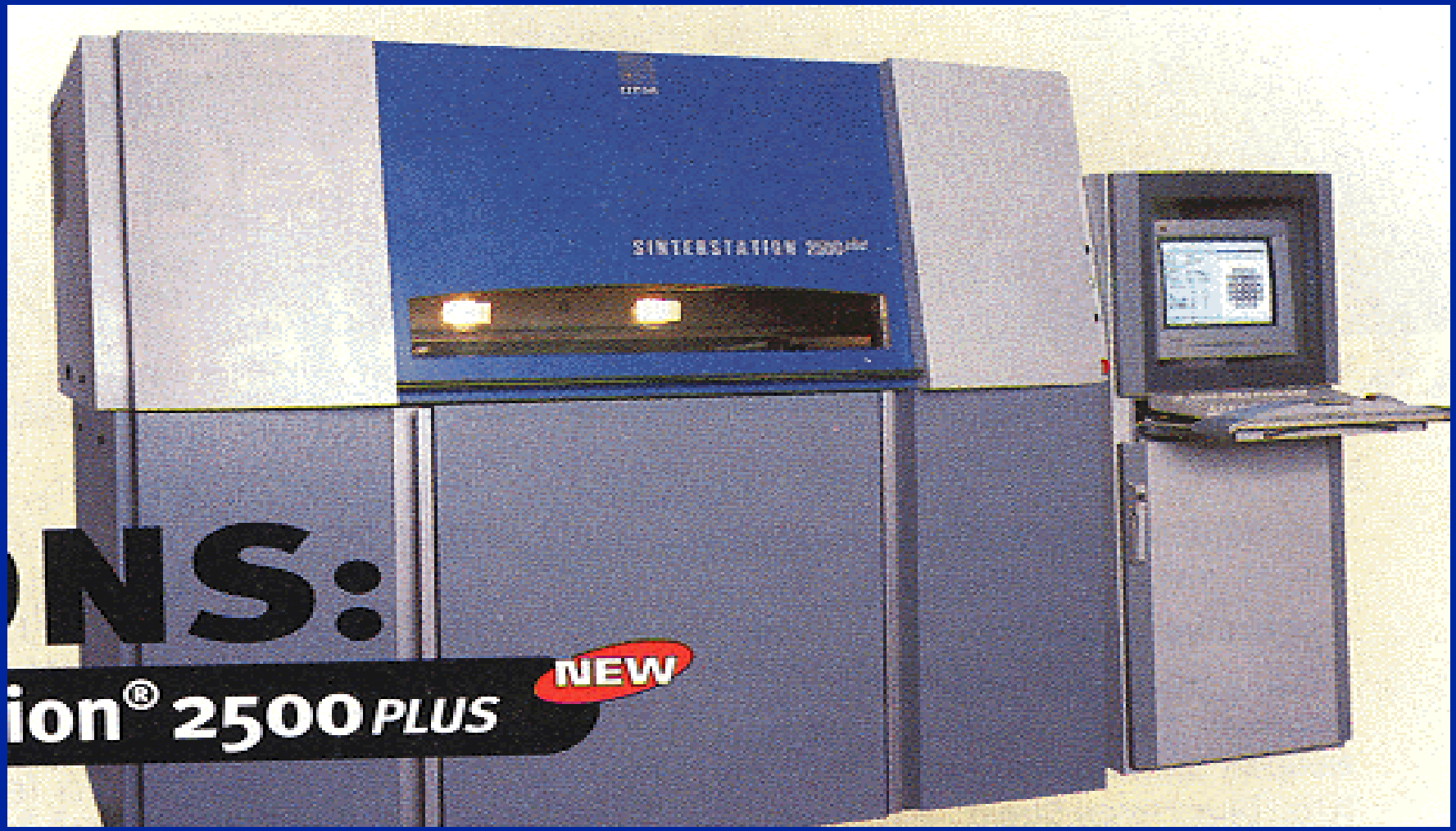
Selective Laser Sintering, SLS



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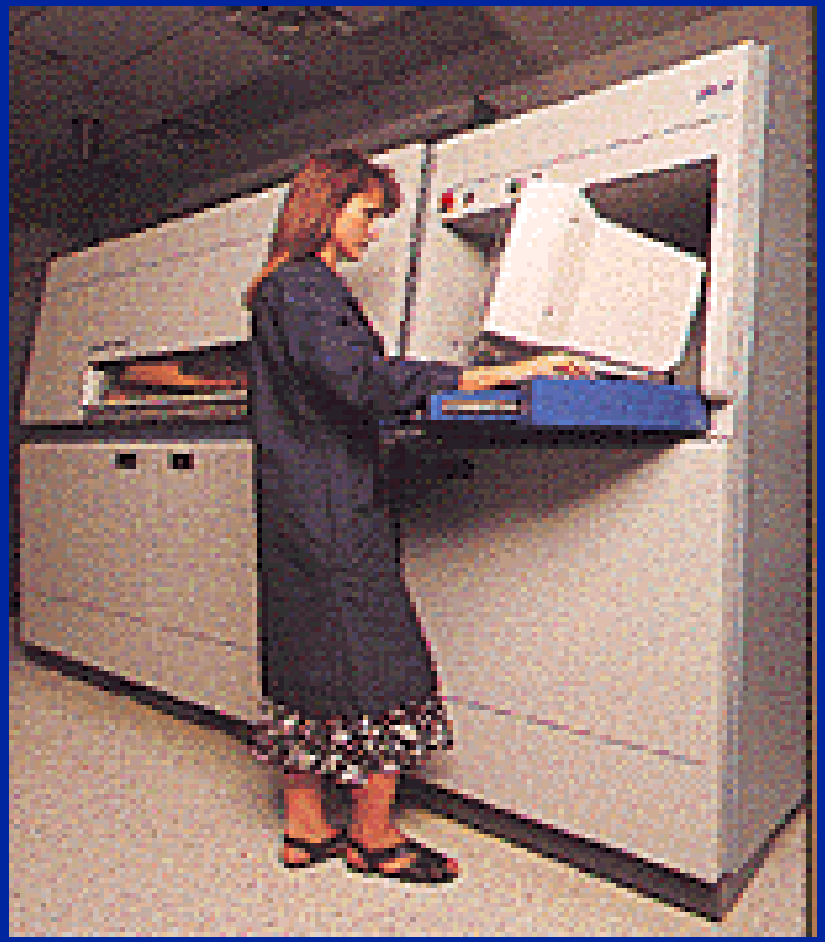
Selective Laser Sintering, SLS



Selective Laser Sintering, SLS

ADVANTAGES

- Functional Materials: Nylon, Glass-filled Nylon,Stainless Steel infiltrated with Bronze
- Post Processing for Metals
- No Post Curing Needed
- New materials being developed:
  - Fully dense Aluminum (Penn State)
  - Fully dense Steel (Rockwell)

Selective Laser Sintering, SLS

- DISADVANTAGES
  - Tolerancing (big improvements in last few years
  - Mechanical properties are not that of injection molded materials
  - Metals up to now are not fully dense & must be infiltrated with lower temp metal (stainless steel with bronze/copper, copper polyamide)
  - Material changeover is difficult

OPTOMEC

Direct Material Deposition (DMD)

- Lens Technology (Sandia Labs)
- Functional Materials: Fully Dense Stainless Steel, Tool Steel, Titanium & other materials
- 2 different Models available the larger one is 18”x18”x42” (460x460x1070mm)
- Larger than previous RP machines

Disadvantages

- Near net finish: Needs finish machine pass

OPTOMEC Model 850

FEATURES

- 1000 Watts - cw Nd:YAG Laser Power
- Fiber Optic Beam Delivery
- 18"x18"x42"(z axis) build envelope
- Up to 5 Axis of Laser & Powder delivery
- Tilt / Rotary Fixturing Stage
- 2 Powder Feed Units for gradient depostion
- Hermetically sealed Class I Laser Enclosure
- Controlled Atmosphere Environment with Oxygen Sensor for process control
- Filtering System for Particulate Control
- Industrial Hardened Windows NT workstation and electronics with front panel for easy access and monitoring.

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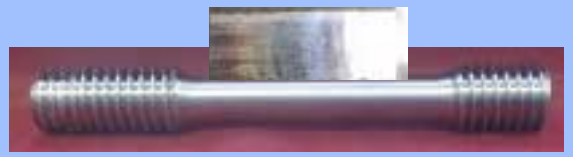
OPTOMEC

- The process generates small uniform grain size, typically in the 3-5 micron range and Rockwell hardness of 50 to 56 for H-13 tool steel
- Uniform grain size on all powder metal RP systems gives better quality material properties (even better than wrought).

Optomec (LENS) Advantages

- Additive 3D fabrication of embedded structures. Integrate sensors (ie:strain gauge) in fabricated parts.

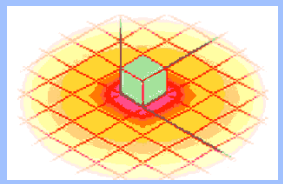
- Computer controlled gradient deposition of multiple materials within a single part.



- Exceptional material properties.

Material Type	Ultimate Strength (ksi)	Yield Strength (ksi)	Elongation (% in one inch)
Optomec LENS 316 Stainless Steel	115	72	50
316 SS Wrought Stock	*85*	*35*	*50*
Optomec LENS Inconel 625	135	84	38
Inconel 625 Wrought Stock	*121*	*58*	*30*
Optomec LENS Ti-6Al-4V	170	155	11
Ti-6Al-4V Wrought Stock	*130*	*120*	*10*

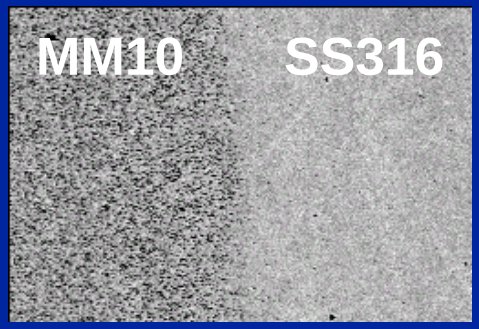
- Small Heat Affected Zone (HAZ).



Partial List of Metals and Alloys Processed

- Stainless Steel 304, 316, 420
- Iron-Nickel Alloys
- Tool Steels H13 & MM10
- Inconel 625, 690 & 718
- Titanium Alloys
- Tungsten
- Haynes 230
- Nickel Aluminide
- Titanium Aluminide
- Mar-M 247
- Copper
- Aluminum

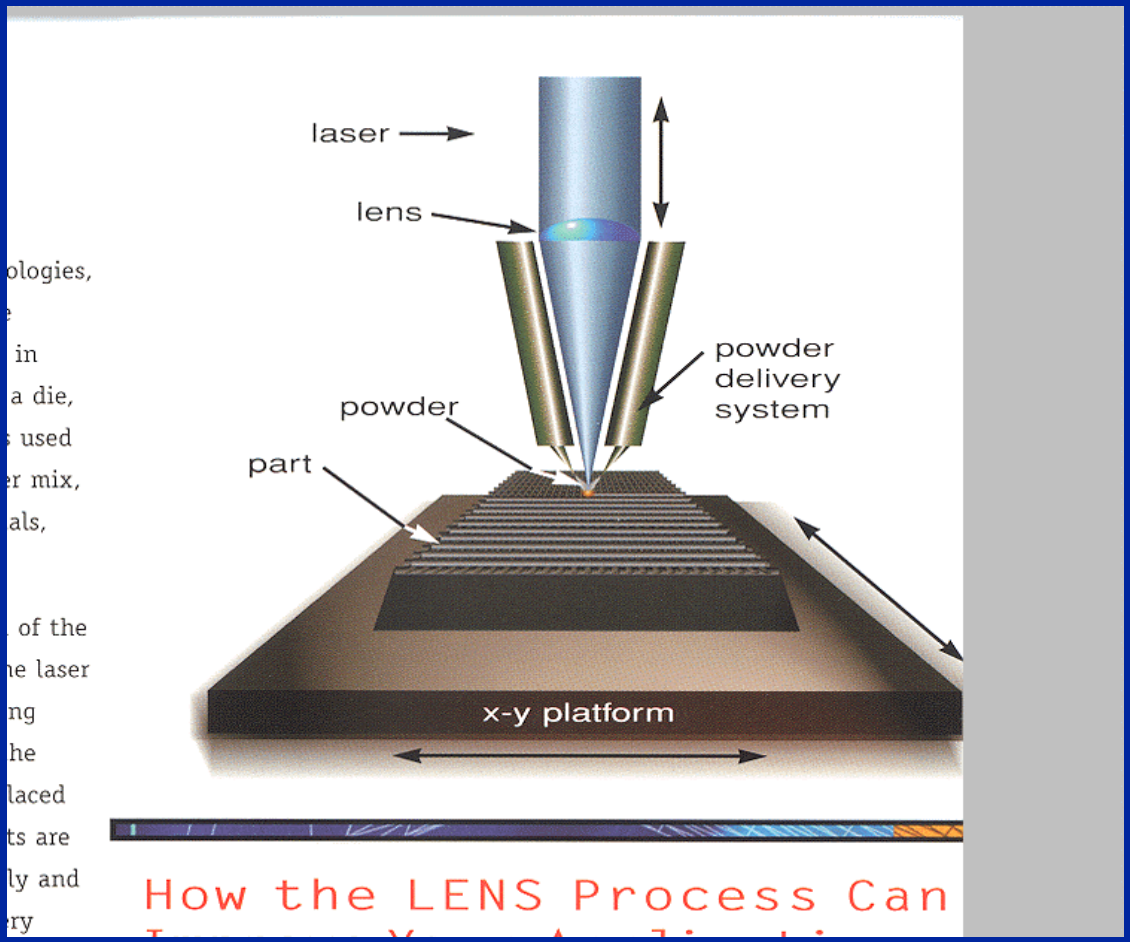
Wear Resistant Layered Structure:
MM10 Tool Steel on SS316



500x

The Optomec LENS pneumatic powder delivery system is optimized for spherical powder with a minimum 36 micron diameter (325 mesh) to a maximum of 150 micron diameter (-100 mesh).

OPTOMEC



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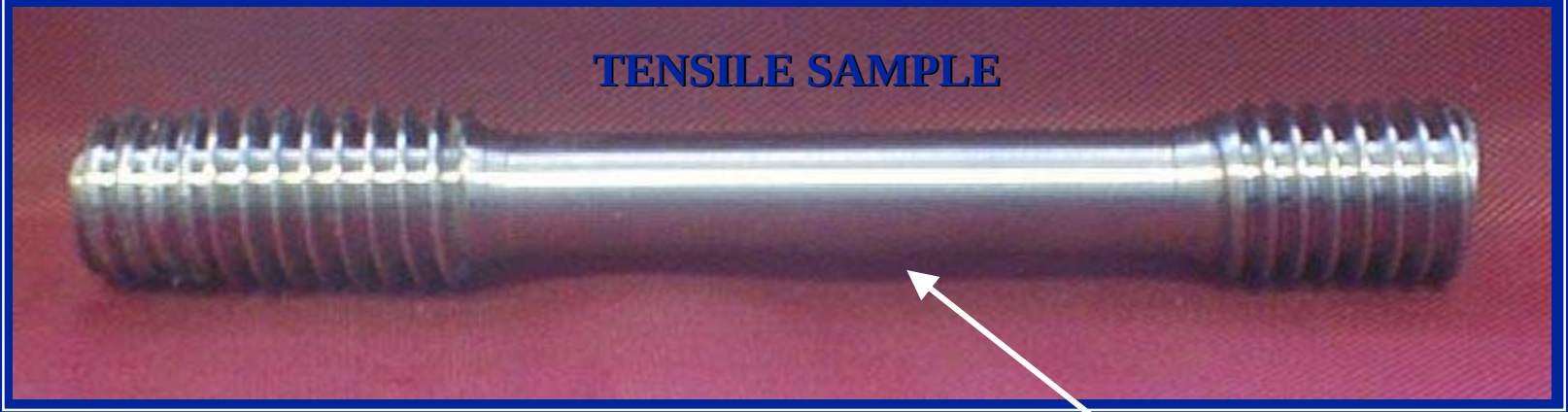
1st known computer controlled gradient fabrication

Ti-*48Al-2Cr-2Nb* *gamma titanium aluminide*

Ti-*6Al-2Sn-4Zr-2Mo* - *Ti-22Al-23Nb* *orthorhombic titanium aluminide*



Elevated Temperature Test from Westmorland Labs

The gradient sample test was for Ti-6-2-4-2 to Ti-22-23. The tensile strength was approximately 80 ksi with the yield strength at 95 ksi. Elongation was 12%.

Gradient Cross Section

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OPTOMEC

Optomec

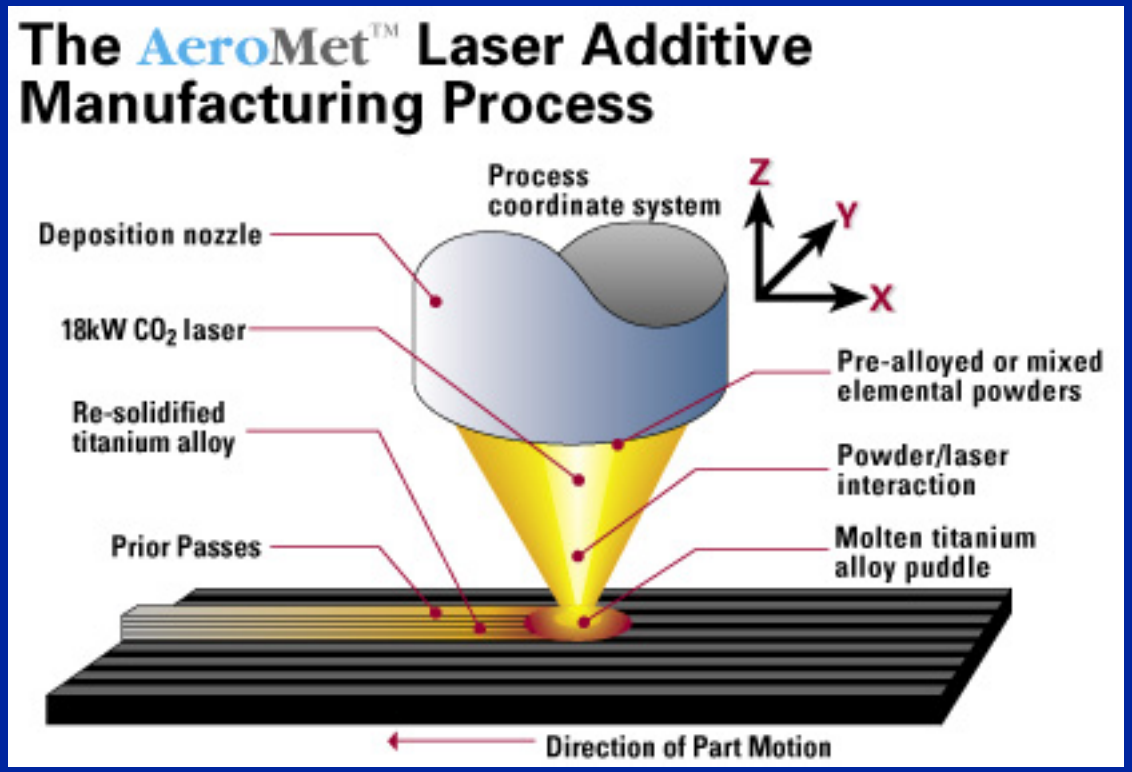
Aeromet

Largest of all RP Systems

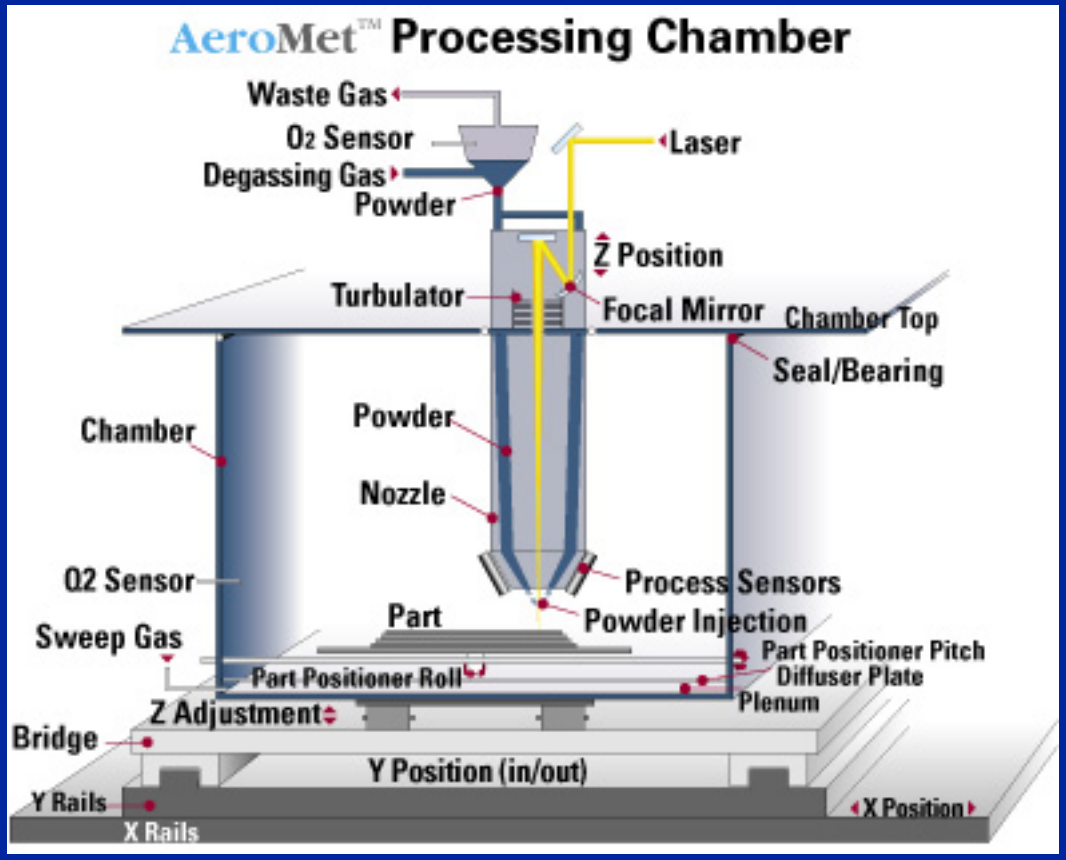
- 10’ x 10’ x 4’ build volume
- Near net finish: Needs finish machine pass
- Titanium and Titanium Alloys

Aeromet

Aeromet


The AeroMet™ Laser Additive Manufacturing Process
Process coordinate system
Z
Y
X
Deposition nozzle
18kW CO_2 laser
Re-solidified titanium alloy
Prior Passes
Pre-alloyed or mixed elemental powders
Powder/laser interaction
Molten titanium alloy puddle
Direction of Part Motion

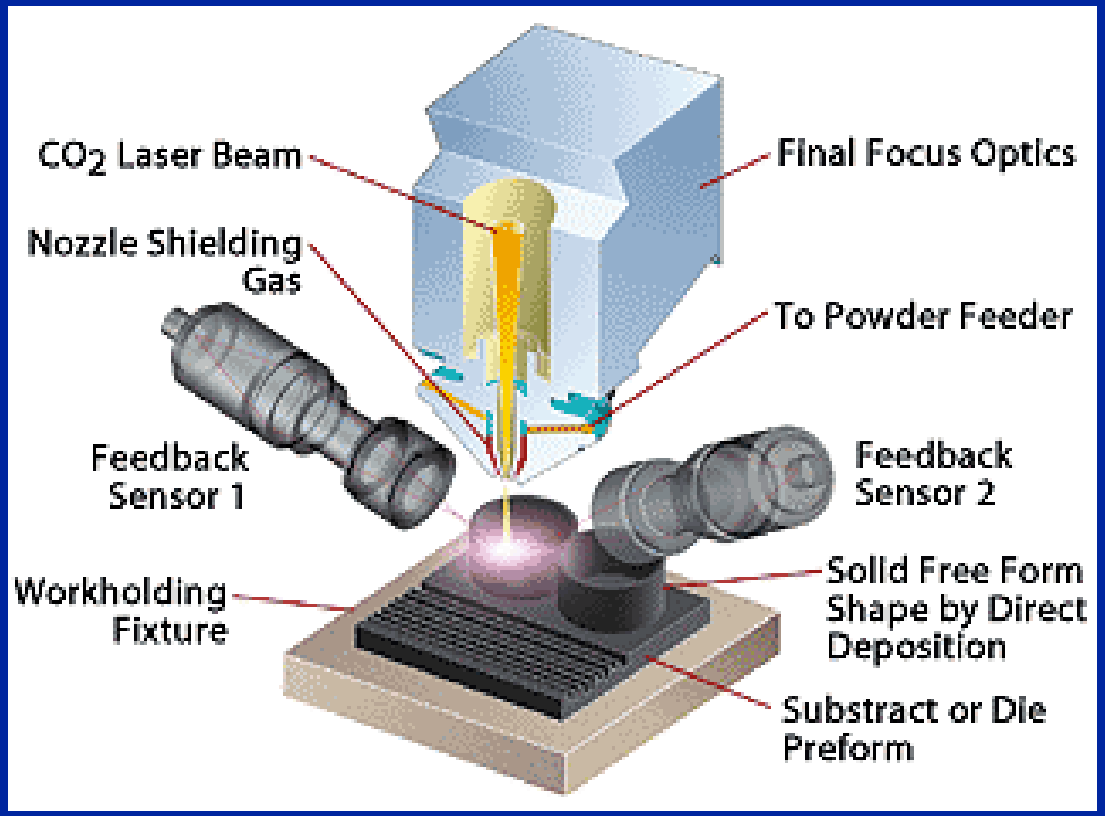
Aeromet


AeroMet™ Processing Chamber
Waste Gas
O2 Sensor
Degassing Gas
Powder
Laser
Z Position
Turbulator
Focal Mirror
Chamber Top
Seal/Bearing
Chamber
Powder
Nozzle
O2 Sensor
Process Sensors
Part
Powder Injection
Sweep Gas
Part Positioner Pitch
Diffuser Plate
Part Positioner Roll
Plenum
Z Adjustment
Bridge
Y Position (in/out)
Y Rails
X Position
X Rails

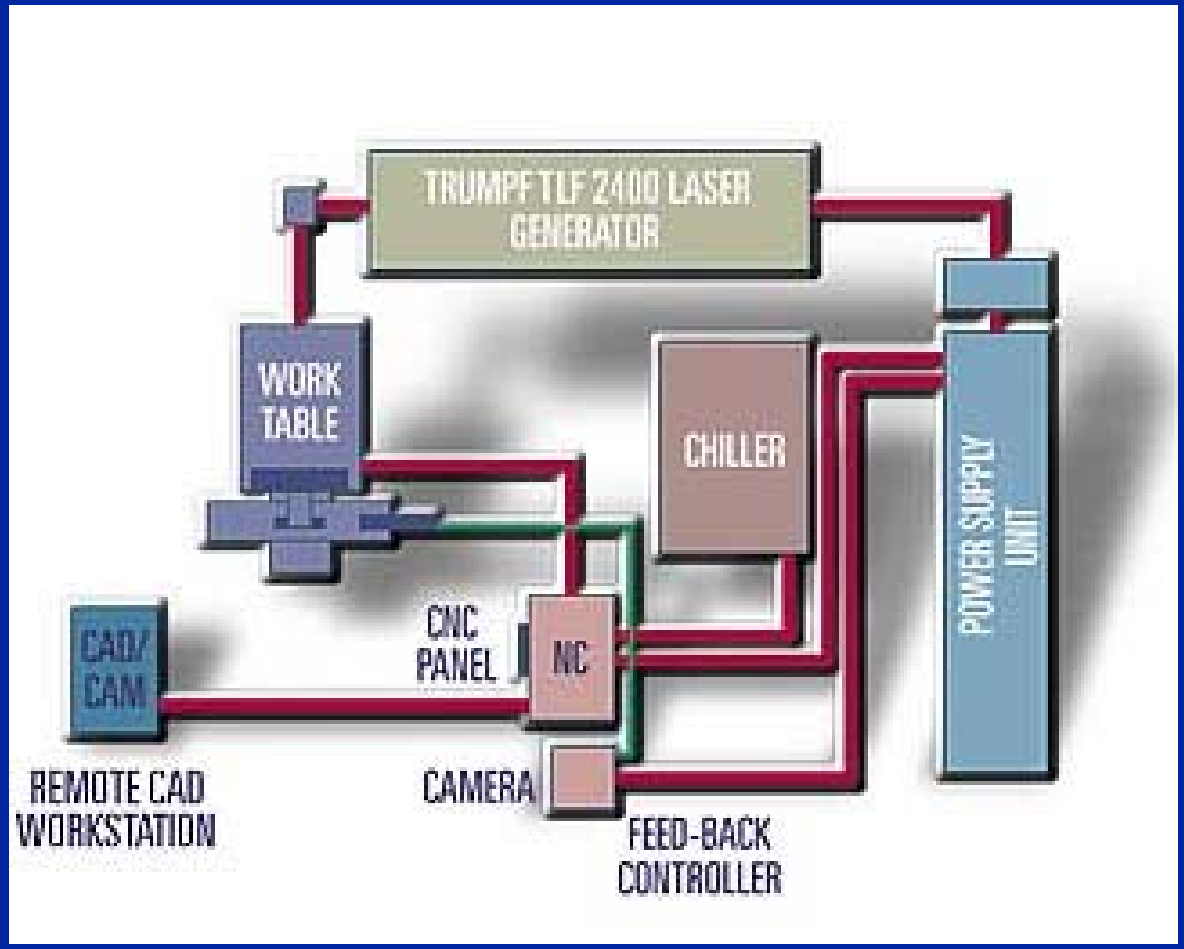
POM (Precision Optical Manufacturing)

- Present machine 2’ x 2’ x 2’ build volume
- New machines next year:
  - 20”x60”x18” (inches)
  - 12’x7.5’x4’ (feet)
- Near net finish: Needs finish machine pass with CNC or EDM
- Programmable for 3 simultaneous materials with gradual change in alloy percentages
- Most metals except titanium
- Primarily for tool repair (e.g. 10 days vs 10wks)

POM


CO_2 Laser Beam
Final Focus Optics
Nozzle Shielding Gas
To Powder Feeder
Feedback Sensor 1
Feedback Sensor 2
Workholding Fixture
Solid Free Form Shape by Direct Deposition
Substract or Die Preform

POM



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OptoForm

- RP using pastes made of ceramics, plastics and metal powders
- Powder plus liquid = paste (liquid is a polymer)
- Filled materials can be sintered in furnace to obtain ceramic or metallic parts, fully dense
- Founded May 1997, 1 ½ yrs to develop 1st prototype
- 4 beta machines sold
- Pastes a key to new chemical advances for RP

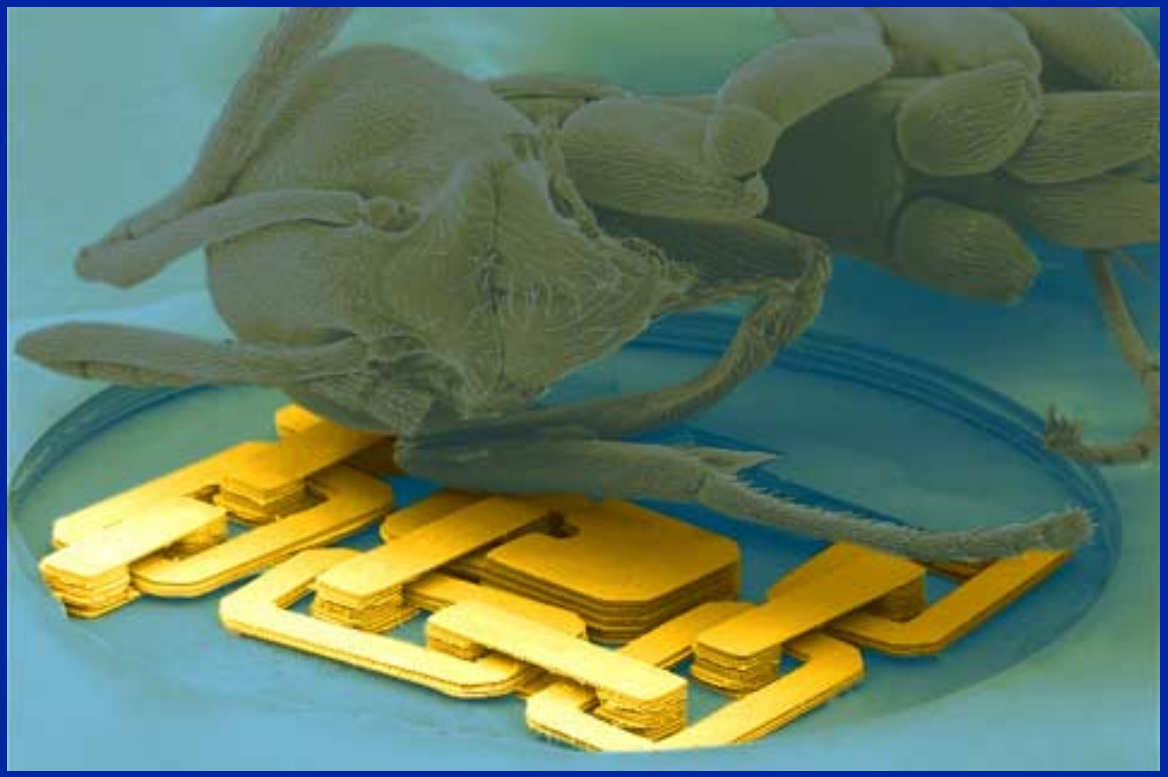
Solidica (www.solidica.com/)

- New technology in development this year with brand new process
- Bonds thin layers of aluminum sheet film
- Using RP's additive processing technique combined with high speed milling to allow customers to produce aluminum cores and cavities in a single machine, with a single set up.

MEMS-Microelectromechanical Systems

- Molecular Beam Epitaxy
  - Atomic spray painting on surfaces (CVD)
  - Creates lasers that read Compact Discs
  - Layer Limitation
- EFAB (Electrochemical Fabrication) at USC's Information Sciences Institute
  - Layers of 5 microns thick (1 micron=1millionth of a meter). A human hair=50 to 100 microns.

EFAB (Electrochemical Fabrication)



- **A small household ant lies over a 12-layer micro-chain with independently-movable links**

Rapid Prototyping (RP)

What Can RP Do For You ?

- Reduce Cycle Time
  - Fewer Engineering Errors
  - Less Machining Time
  - Faster and More Accurate Vendor Bids: 15-20% reduction in bids when vendor sees the actual model of the work he's asked to do
  - Faster Tooling
  - Reduce Cost
  - Less Engineering Rework (Physical Parts for Design Reviews)
  - Less Scrap (Near Net Ti Ribs)
  - Direct Tooling (Hole Drilling)
  - Direct Fly-Away Parts
  - Better Producibility
  - Assembly Fit Checks

Rapid Prototyping (RP)

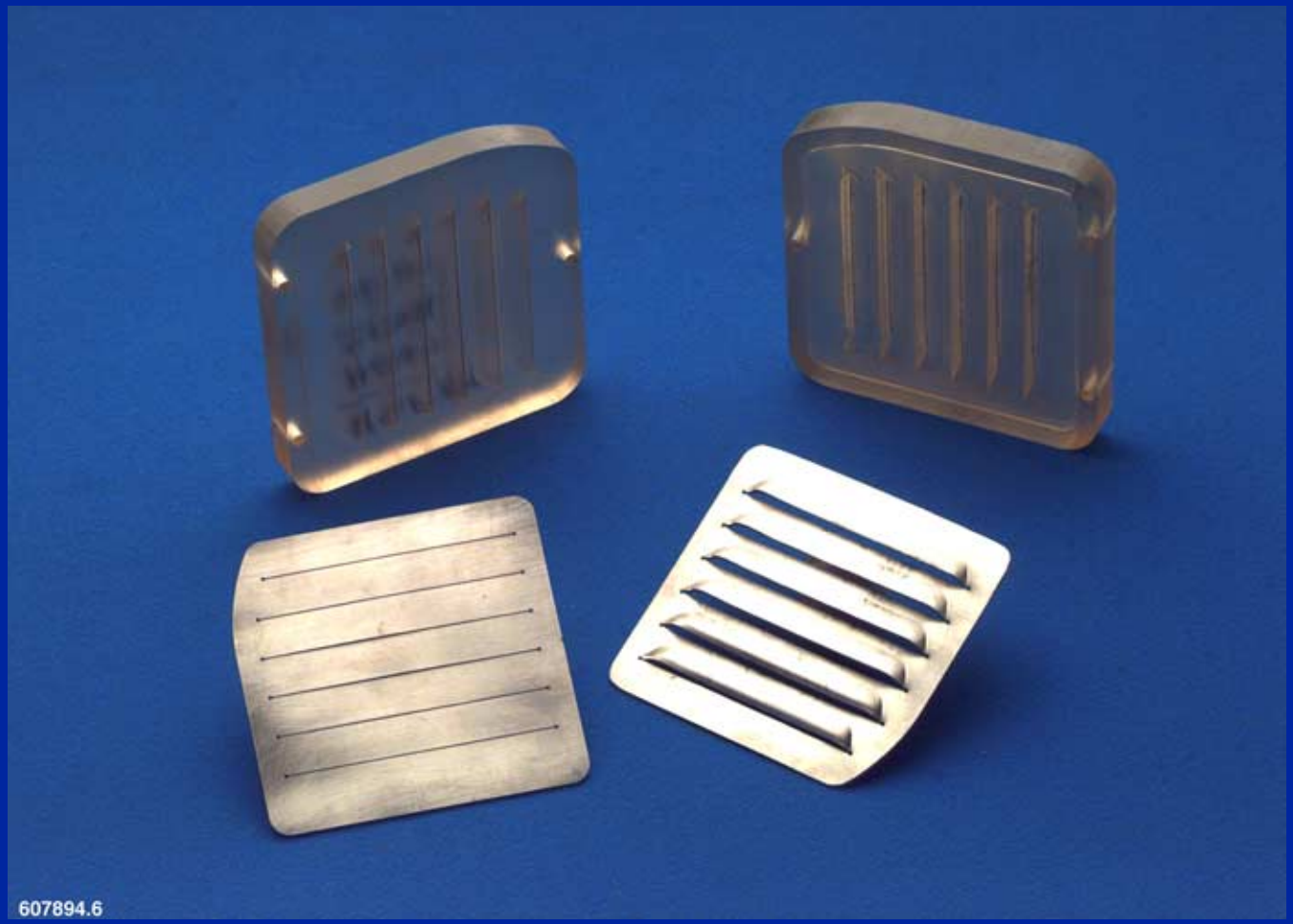
What Can RP Do For You ?

- Promote Assessment of Multiple Design Concepts
  - Average 6 Hours Labor and 24 to 36 Hour Turnaround
  - Machines run 7 days, 24 hours/day unattended
  - Physical Models Produce Better Designs
  - Desktop Systems Available, No Technician Required
    - 3D Copy of Your Computer Model in Minutes. Avoid design mistakes at beginning of design cycle
    - Systems by Stratasys and 3DSystems

Sheet Metal Forming as example for reducing product cycle

- With forming operations one begins with a relatively simple shape – a sheet metal blank, which is then plastically deformed through one or more operations into a relatively complex configuration. This process drastically reduces metal removal requirements and brings the product to near net or net shape dimensions. However, metal forming usually requires relatively expensive tooling.
- Question: How to get the biggest bang for your buck?
- Answer: Look at the highest cost in the design cycle. Modern Flex forming machines are very efficient. Highest cost are the design & the creation of the tool. By using a software such as FemForm, a metal forming simulation software, the design of the tool is taken care of, including the optimization of the tool. Next is the actual creation of the tool using RP to grow the part overnight in order to begin stamping the parts the next morning. In this way we are able to design and produce a custom louver die overnight, from concept to end product in 24 hours!

Sheet Metal Forming as example for reducing product cycle



Rapid Prototyping (RP)

Success Stories

- High Lift Wing (1995 First Place Award for North America)
  - $12K RP vs. $450K Conventional
- Form Blocks (1997 2nd Place Award, N. America) 98% labor hour savings creating custom louver
- Assembly Fit-Check
- Low-Speed Wind Tunnel Models
  - 1000 hrs. RP vs. 15000 hrs. Conventional (106 models)
- Aircraft Locator Tooling (2000 3rd place World Award)
  - 40% Touch Labor Savings Over Hand Locating
  - Unquantified Cost Avoidance Due to Less Rework
  - 8 hrs. RP vs. 16 weeks for Conventional Tooling
  - 24 Hour Replacement on Damaged Tools
- Aircraft Field Repair using RP (2001 1st place World Award)

Cost Savings of RP for 1996 in man-hours (15 months)

Conventional fab of 106 models:	15,600 hr.
RP method man-hours:	1,000 hr.
Total hours saved using RP:	14,600 hr.
Total dollars saved (14,600 x $75/hr):	$1.1 million

Rapid Prototyping (RP)

Where Are We Going With RP ?

- Produce Parts Under Load (High Speed Wind Tunnel)
- Produce Rapid Metallic Parts (Near Net Titanium Fittings)
- Produce Rapid Fly-Away Parts for Demonstrator Vehicles
- “Grow” IR Models with Internal Passages
- Provide Support for Higher Fidelity Design Reviews
- Improve Producibility Analysis
- Produce Faster and Better Proposals with Higher Fidelity Designs and Physical Prototypes
- Facilitate a LEAN Product Development Cycle
- Conforming Cooling Channels for Plastic Injection Molding

Rapid Prototyping (RP)

Where Are We Going With RP ?

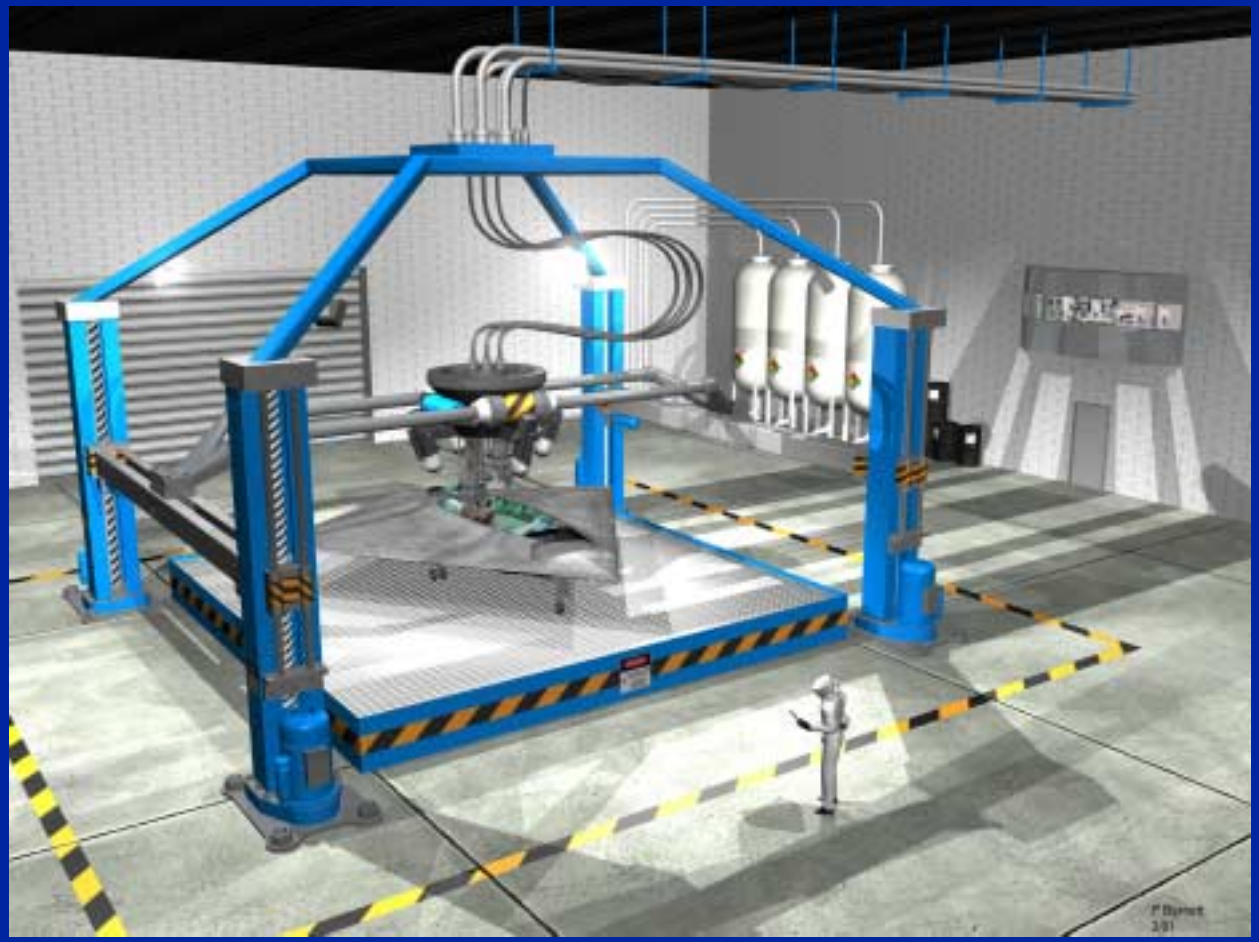
- R&D Northrop Grumman and Loyola Marymount University: Experimenting with Cryogenic Processing to Improve Durability of RP materials
- We must take this technology seriously and make RP part of the required design & production cycle to take advantage of the remarkable cost savings.

Rapid Prototyping (RP)

Where Are We Going With RP ?

- Future vision of RP: one room size machine makes multiple material product layer by layer fully assembled.
- Star Treck replicator in your garage?
- Movie: Fifth Element- growing a human being layer by layer from DNA material in their finger (all that was left of them). Someday, growing houses and space ships etc. with our own type of programmed DNA code.

RP in the Future



Organizations to contact for RP

- Rapid Prototyping Association (RPA) of the Society of Manufacturing Engineers (SME www.sme.org/rpa)
- Global Alliance of Rapid Prototyping Associations (GARPA- www.garpa.org) consisting of 16 countries. This year's Global Summit is hosted by South Africa. Next year China is hosting.